Filter Type II Design

Optional Midsem Submission

EE338: Digital Signal Processing

Report

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1 | Introduction

We are given a M value that gives most of the specifications of the filter. The Band Specifications: All frequencies are in kiloHertz (kHz). There are two groups of frequency bands, which will be used in specifying the filters ahead. For each group of frequency bands, we pass the argument, which is an integer ranging from 0 to 10. The frequency band in each group is specified according to the argument.
Group I of Frequency Bands: The frequency band in this group is (40 + 5D) to (70 + 5D)
Group II of Frequency Bands: The frequency band in this group is (170 + 5D) to (200 + 5D).

$$M = 11Q + R$$

The frequency band from Group I can be obtained by passing the argument D = Q and the frequency band from Group II can be obtained by passing the argument D = R.
For given $\mathbf{M = 114}$, we get $\mathbf{Q = 10}$ and $\mathbf{R = 4}$.
An analog signal is bandlimited to 280 kHz. It is ideally sampled, with a sampling rate of 630 kHz. We wish to build a series of discrete time filters, as described below, to extract specific frequency bands of an analog signal or to suppress specific frequency bands of the signal.
(i) For all filters, the passband AND stopband tolerances are 0.15 in magnitude. That is, the filter magnitude response (note: NOT magnitude squared) must lie between 1.15 and 0.85 in the passband; and between 0 and 0.15 in the stopband. For the IIR Filter, the passband magnitude response must lie between 1 and 0.85.
(ii) For bandpass filters, the transition bands are 5 kHz on either side of each passband. For bandstop filters, the transition bands are 5 kHz on either side of each stopband.

Group I frequency band range is from 90 to 120
Group II frequency band range is from 190 to 220
Transition band for Group I frequency band is 85 to 90 and 120 to 125
Transition band for Group II frequency band is 185 to 190 and 220 to 225

2 | Filter Design Specifications

Given that $\delta_1 = 0.15$ and $\delta_2 = 0.15$. We have multiple passbands and stopbands:

- $\Omega_{pI1} = 90$
- $\Omega_{pI2} = 120$
- $\Omega_{pII1} = 190$
- $\Omega_{pII2} = 220$
- $\Omega_{sI1} = 85$
- $\Omega_{sI2} = 125$
- $\Omega_{sII1} = 185$
- $\Omega_{sII2} = 225$

The Filter Type II has a oscillatory passband and a monotonic stopband. This can be achived by using chebyschev filter. For designing this filter, I am using a Bandpass and a Bandstop filter in cascade.

$$H_{\text{final,analog}}(\Omega) = H_{\text{BandPass,analog}}(\Omega) \times H_{\text{BandStop,analog}}(\Omega)$$

$$H_{\text{final}}(e^{j\omega}) = H_{\text{BandPass}}(e^{j\omega}) \times H_{\text{BandStop}}(e^{j\omega})$$

$$h_{\text{final}}[n] = h_{\text{BandPass}}[n] * h_{\text{BandStop}}[n]$$

We are now using two filters in cascade, and we want our final filter to satisfy the tolerance requirement. I want to use the same tolerance δ for both the bandpass and bandstop filters. The given derivation relates to filter design, where two filters are cascaded (multiplied in frequency response) to obtain a final response. The goal is to determine an appropriate tolerance δ for each individual filter, ensuring that the overall response meets tolerance = 0.15.

2.1 | Individual Filter Calculation

1. **Passband Condition:** The individual filter has a passband gain of $1 - \delta$. Since two such filters are cascaded, the overall passband gain becomes:

$$(1 - \delta)^2$$

The constraint given is:

$$(1 - \delta)^2 \geq 1 - 0.15 = 0.85$$

Solving for δ:

$$1 - \delta \geq \sqrt{0.85}$$

$$\delta \leq 1 - \sqrt{0.85}$$

2. **Stopband Condition:** - The stopband gain of an individual filter is δ. - The overall stopband gain after cascading two filters is:

$$\delta(1 - \delta)$$

- The constraint given is:

$$\delta(1 - \delta) \leq 0.15$$

From the Passband Constraint: Since $\sqrt{0.85} \approx 0.9219$, we get:

$$\delta \leq 1 - 0.9219 = 0.0781$$

2. From the Stopband Constraint: - Checking if $\delta = 0.078$ satisfies:

$$0.078 \times (1 - 0.078) = 0.078 \times 0.922 = 0.072$$

Since $0.072 < 0.15$, the chosen $\delta = 0.078$ satisfies both constraints.

2.2 | Conclusion

The selected tolerance is $\delta = 0.078$ for the individual filters. This ensures that the final cascaded filter meets both the passband and stopband tolerance requirements.

3 | Procedure

We first list the frequencies which form the passband and the stopband edges. We then convert it to normalised frequency to make it independent of the sampling rate.

$$\omega = \frac{2\pi f}{f_s}$$

Now we convert this to analog anglular frequency. This is because we know the characteristics of analog filters and they can then be converted to digital filters by using bilinear transformation. So to obtain angular analog frequency, we do the following:

$$s = \frac{1 - z^{-1}}{1 + z^{-1}}$$

For $z = e^{j\omega}$, we get $s = jtan(\omega/2)$
For $s = j\Omega$, we get $\Omega = tan(\omega/2)$
The table for the bands is given below:

Category	Type	Un-normalised Frequency (kHz) [f]	Normalised Frequency (rad/s) [ω]	Analog Angular Frequency (rad/s) [Ω]
Stopband for Group 1	Monotonic	0-85	0.0-0.8477	0.0-0.4512
Passband for Group 1	Monotonic	90-120	0.8976-1.1968	0.4816-0.6818
Stopband Intermediate	Monotonic	125-185	1.2467-1.8451	0.7190-1.3202
Passband for Group 2	Monotonic	190-220	1.8949-2.1941	1.3909-1.9506
Stopband for Group 2	Monotonic	225-315	2.2440-3.1416	2.0765-∞

Table 3.1: Frequency Table with Normalized and Analog Angular Frequencies

4 | Target Filter

The filter for which we aim is the following:

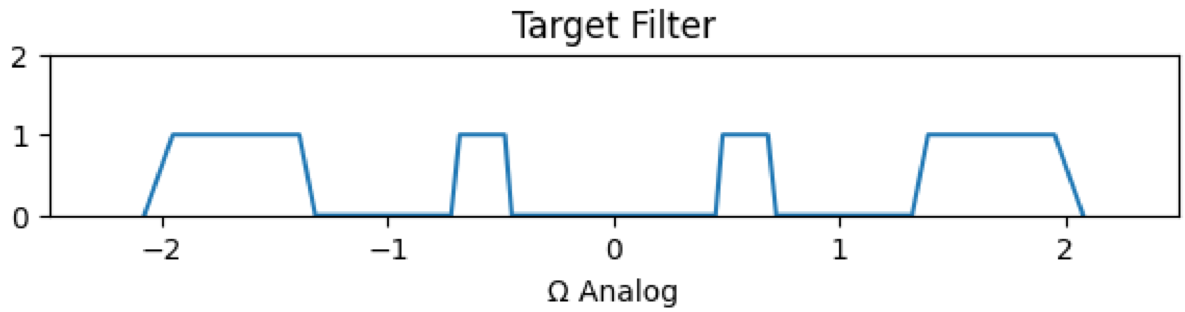


Figure 4.1: Target Filter

We achieve this filter by cascading a bandpass and bandstop filter.

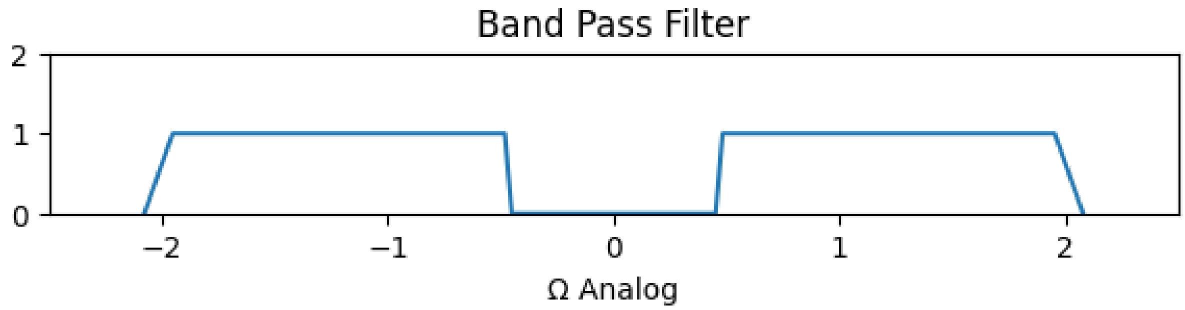


Figure 4.2: BandPass Filter

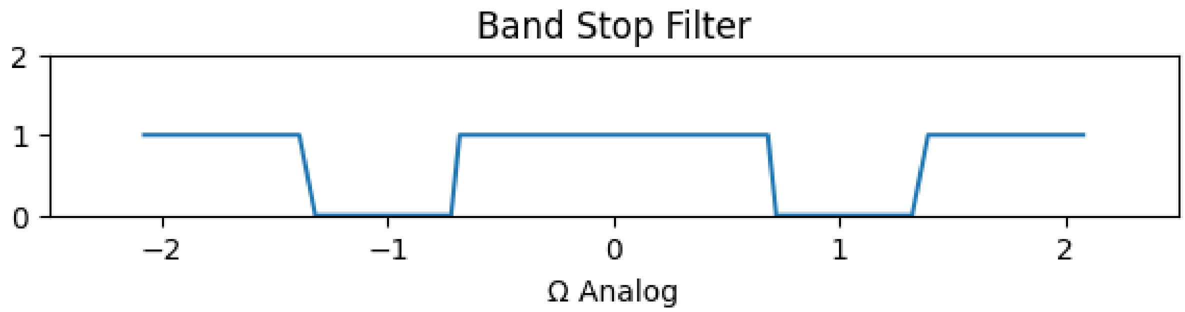


Figure 4.3: BandStop Filter

5 | BandPass Filter

We first make a low pass filter and then apply frequency transformation on this low pass filter to obtain the bandpass filter.

$$\Omega_L = \frac{\Omega^2 - \Omega_0^2}{B\Omega}$$

$$\Omega = \frac{s}{j}, \quad \Omega_L = \frac{s_L}{j}$$

$$\frac{s_L}{j} = \frac{(s/j)^2 - \Omega_0^2}{Bs/j}$$

$$\Rightarrow s_L = \frac{s^2 + \Omega_0^2}{Bs}$$

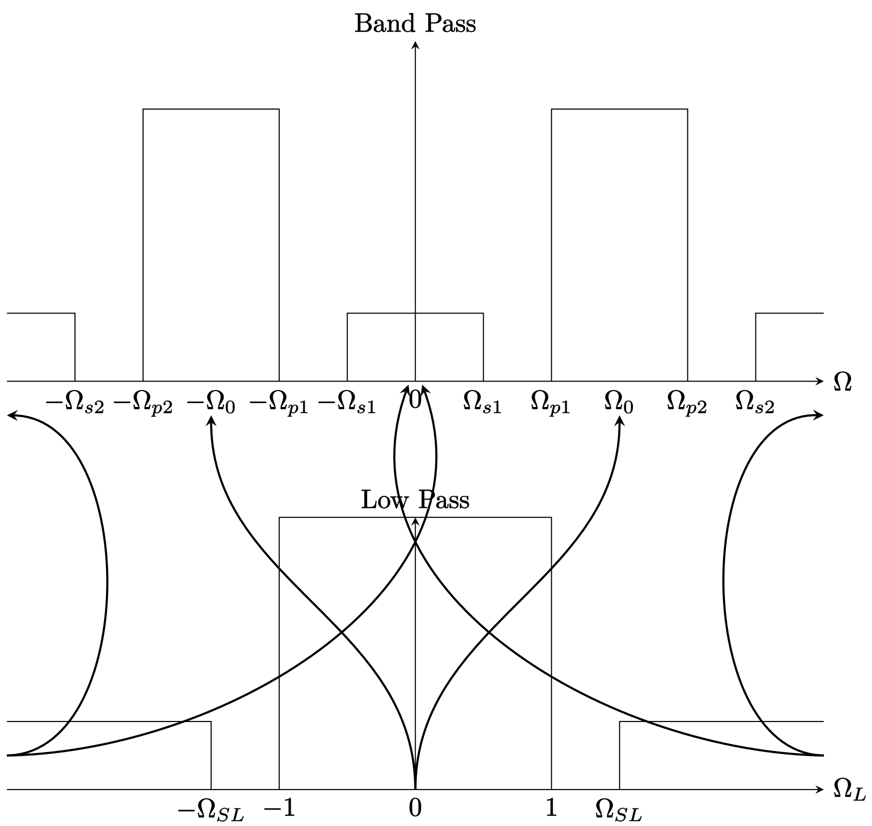
The transformation should satisfy the following criteria to be a valid frequency transformation
1. The transformation should be rational.
2. Imaginary axis of first filter should be mapped to the imaginary axis of the transformed filter
3. The stability should be preserved i.e. the LHP and RHP of s should be mapped the the LHP and RHP of s_l respectively. The real part of s and s_l should have same sign

5.1 | Justification for this transformation approach

The transformation $\Omega_L = \frac{\Omega^2 - \Omega_0^2}{B\Omega}$ does the following mapping:

Ω_L	Ω
∞	0^+
0	Ω_0
$-\infty$	∞

which is clearly a transformation from lowpass to bandpass filter.



$$\Omega_0^2 = \Omega_{pI1} \cdot \Omega_{pII2} = 0.9393460459741229$$

$$B = \Omega_{pI1} - \Omega_{pII2} = 1.4689975444433596$$

5.2 | Low Pass filter

Chebyschev Low pass filter equation: using this filter as it has oscillatory behaviour in passband and monotonic in stopband

$$|H_{\text{analog, LPF}}(s)|^2 = \frac{1}{1+\epsilon^2 C_N^2(\frac{s}{j\Omega_p})}$$

For getting required tolerance limit, and passband and stopband edges, we need the following conditions to be fulfilled:

$$\epsilon \leq \sqrt{D_1}$$

$$N \geq \frac{\cosh^{-1}\left(\sqrt{\frac{D_2}{D_1}}\right)}{\cosh^{-1}\left(\frac{\Omega_S}{\Omega_P}\right)}$$

where $D_1 = \frac{1}{(1+\delta)^2} - 1$ and $D_2 = \frac{1}{\delta^2} - 1$. As per our calculations above, we use $\delta = 0.078$, and we get the following values:

- The value of D_1 is 0.1763543367478977 and D_2 is 163.3655489809336
- We choose N as the smallest integer which satisfies the above condition:

$$N_{min} = \left\lceil \frac{\cosh^{-1}\sqrt{\frac{D_2}{D_1}}}{\cosh^{-1}\left(\frac{\Omega_s}{\Omega_p}\right)} \right\rceil$$

  , we get N = 10 and we choose $\epsilon = \sqrt{D_1} = 0.4199456354671372$

- We use $\Omega_p = 1$ and $\Omega_s = \min\left(\left|\frac{\Omega_{pI1}^2 - \Omega_0^2}{B\Omega_{pI1}}\right|, \left|\frac{\Omega_{pII2}^2 - \Omega_0^2}{B\Omega_{pII2}}\right|\right) = 1.1056221221727247$

We find the poles of the transfer function $|H_{analog,LPF}(s)|^2$.

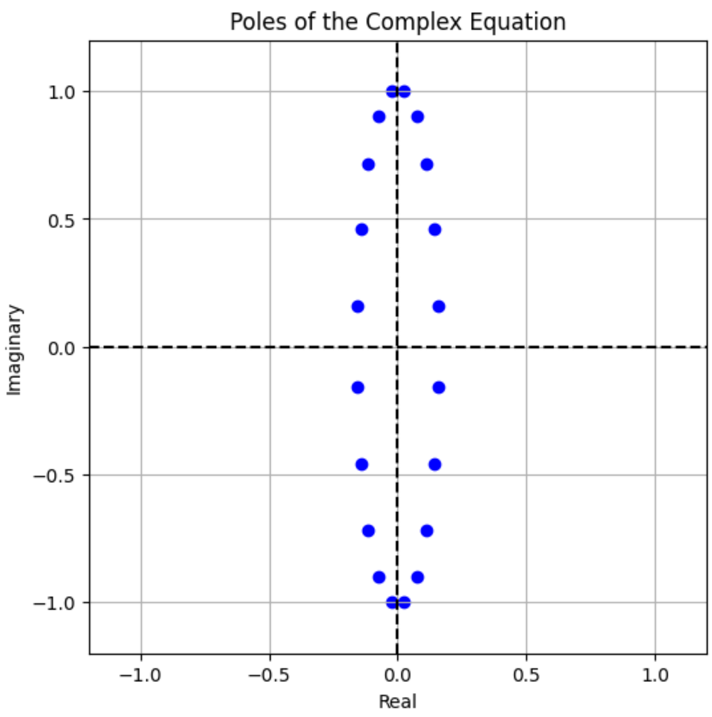


Figure 5.1: Poles of transfer function

For having a stable response, we use the left poles to make our Low pass filter:

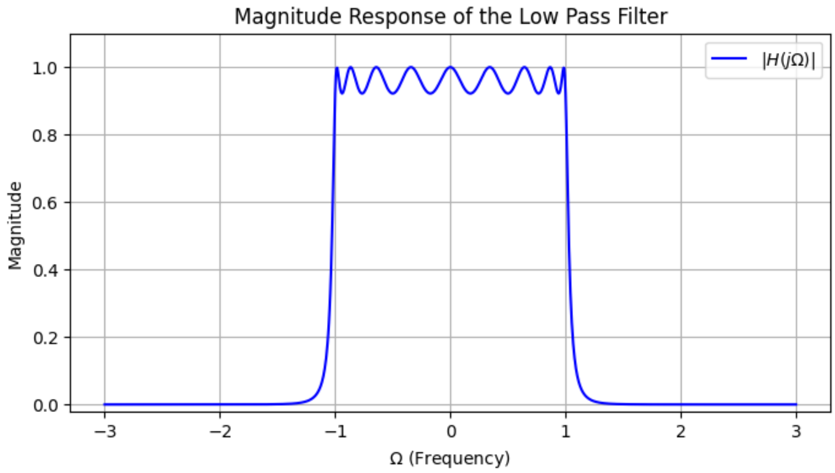


Figure 5.2: Low Pass Filter

The transfer function of this low pass filter is :

$$\frac{0.00465089962853737 + 8.19700210485941 \times 10^{-18} i}{\begin{aligned} & s^{10} + s^{9}(1.02859055531433 + 8.88178419700125 \times 10^{-16} i) \\ & + s^{8}(3.02899926524092 + 8.88178419700125 \times 10^{-16} i) \\ & + s^{7}(2.40403742012023 + 4.44089209850063 \times 10^{-15} i) \\ & + s^{6}(3.19785191054288 + 3.5527136788005 \times 10^{-15} i) \\ & + s^{5}(1.86956598968533 + 3.33066907387547 \times 10^{-15} i) \\ & + s^{4}(1.37642479081273 + 1.33226762955019 \times 10^{-15} i) \\ & + s^{3}(0.536853316668658 + 8.60422844084496 \times 10^{-16} i) \\ & + s^{2}(0.207750123789674 + 2.98372437868011 \times 10^{-16} i) \\ & + s(0.0414060740830247 + 6.93889390390723 \times 10^{-17} i) \\ & + (0.00504435968388001 + 8.89045781438114 \times 10^{-18} i) \end{aligned}}$$

5.3 | BandPass Filter

We apply the above mentioned transform on the ”s” variable in the equation of the Low pass analog filter. This gives us the following fiter magnitude response:
The coefficients of the Band Pass Filter are:

Coefficient Index	Numerator Coefficient
0	$0.00465089962853737 + 8.19700210485941 \times 10^{-18} i$
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0

Table 5.1: Numerator Coefficients of the Analog BandPass Filter

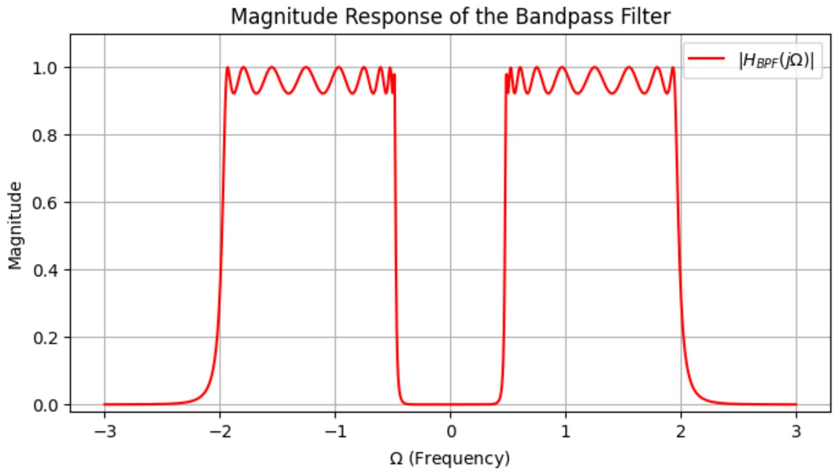


Figure 5.3: Band Pass Filter

6 | Band Stop Filter

We first make a low pass filter and then apply frequency transformation on this low pass filter to obtain the bandstop filter.

$$\Omega_L = \frac{B\Omega}{\Omega_0^2 - \Omega^2}$$

$$\Omega = \frac{s}{j}, \quad \Omega_L = \frac{s_L}{j}$$

$$\frac{s_L}{j} = \frac{Bs/j}{\Omega_0^2 - (s/j)^2}$$

$$\Rightarrow s_L = \frac{Bs}{s^2 + \Omega_0^2}$$

The transformation should satisfy the following criteria to be a valid frequency transformation
1. The transformation should be rational.
2. Imaginary axis of first filter should be mapped to the imaginary axis of the transformed filter
3. The stability should be preserved i.e. the LHP and RHP of s should be mapped the the LHP and RHP of s_l respectively. The real part of s and s_l should have same sign

6.1 | Justification for this transformation approach

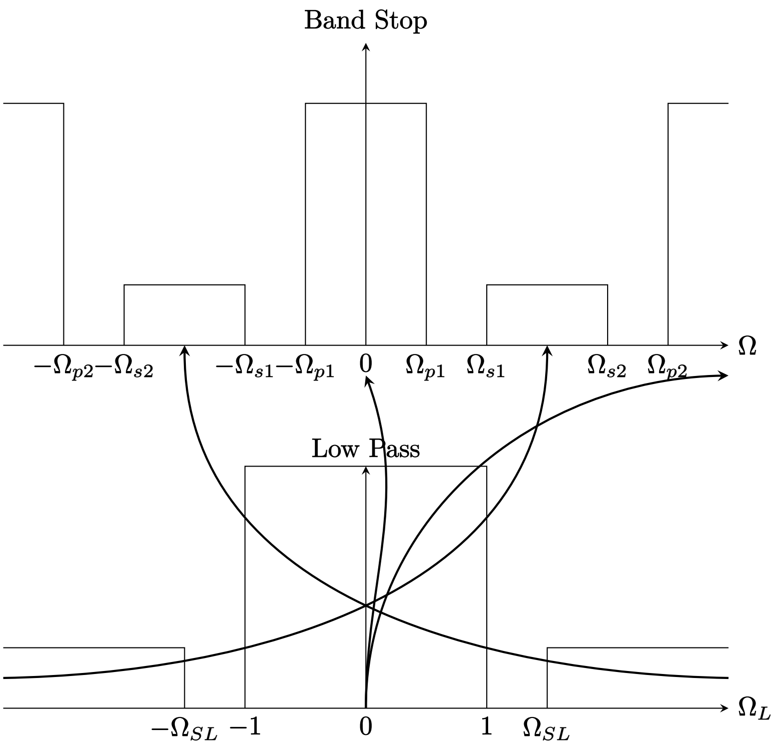
The transformation $\Omega_L = \frac{B\Omega}{\Omega_0^2 - \Omega^2}$ does the following mapping:

Ω_L	Ω
0^+	0
0^-	∞
∞	Ω_0^-
$-\infty$	Ω_0^+

which is clearly a transformation from lowpass to bandstop filter.

Coefficient Index	Denominator Coefficient
0	0.0213692510712546
1	$0.0322888742607925 + 2.78811439271701 \times 10^{-17}i$
2	$0.340410051673331 + 4.09573319652848 \times 10^{-17}i$
3	$0.435826076550727 + 5.36541481166778 \times 10^{-16}i$
4	$2.21637969884517 + 6.61320980928992 \times 10^{-16}i$
5	$2.36978719640788 + 3.35063069837496 \times 10^{-15}i$
6	$7.6654982797618 + 3.29055723367142 \times 10^{-15}i$
7	$6.71864059914927 + 1.0073711836353 \times 10^{-14}i$
8	$15.3959215880829 + 7.79354088493118 \times 10^{-15}i$
9	$10.8088061152786 + 1.6570467313519 \times 10^{-14}i$
10	$18.5768990639703 + 9.87606661422287 \times 10^{-15}i$
11	$10.1532092860878 + 1.55654029508975 \times 10^{-14}i$
12	$13.5849146365656 + 6.8767944180961 \times 10^{-15}i$
13	$5.56875671170867 + 8.34961322497484 \times 10^{-15}i$
14	$5.96819269824257 + 2.561957349465 \times 10^{-15}i$
15	$1.73315500964508 + 2.45049951707126 \times 10^{-15}i$
16	$1.52264209890089 + 4.54324305069922 \times 10^{-16}i$
17	$0.281249975266826 + 3.4624426216548 \times 10^{-16}i$
18	$0.206351328130356 + 2.48277035480223 \times 10^{-17}i$
19	$0.0183858371178631 + 1.58760000972566 \times 10^{-17}i$
20	0.0114299786158762

Table 5.2: Denominator Coefficients of the Analog BandPass Filter



$$\Omega_0^2 = \Omega_{pI2} \cdot \Omega_{pII1} = 0.9483099953849536$$

$$B = \Omega_{pII1} - \Omega_{pI2} = 0.7091268454434455$$

6.2 | Low Pass filter

Chebyschev Low pass filter equation: using this filter as it has oscillatory behaviour in passband and monotonic in stopband

$$|H_{\text{analog, LPF}}(s)|^2 = \frac{1}{1 + \epsilon^2 C_N^2(\frac{s}{j\Omega_p})}$$

For getting required tolerance limit, and passband and stopband edges, we need the following conditions to be fulfilled:

$$\epsilon \leq \sqrt{D_1}$$

$$N \geq \frac{\cosh^{-1}\left(\sqrt{\frac{D_2}{D_1}}\right)}{\cosh^{-1}\left(\frac{\Omega_S}{\Omega_P}\right)}$$

where $D_1 = \frac{1}{(1+\delta)^2} - 1$ and $D_2 = \frac{1}{\delta^2} - 1$. As per our calculations above, we use $\delta = 0.078$, and we get the following values:

- The value of D_1 is 0.1763543367478977 and D_2 is 163.3655489809336
- We choose N as the smallest integer which satisfies the above condition:

$$N_{min} = \left\lceil \frac{\cosh^{-1}\sqrt{\frac{D_2}{D_1}}}{\cosh^{-1}\left(\frac{\Omega_s}{\Omega_p}\right)} \right\rceil$$

  , we get N = 8 and we choose $\epsilon = \sqrt{D_1} = 0.4199456354671372$
- We use $\Omega_p = 1$ and $\Omega_s = \min\left(\left|\frac{B\Omega_{pII1}}{\Omega_0^2 - \Omega_{pII1}^2}\right|, \left|\frac{B\Omega_{pI2}}{\Omega_0^2 - \Omega_{pI2}^2}\right|\right) = 0.8462066391530495$

We find the poles of the transfer function $|H_{analog,LPF}(s)|^2$.

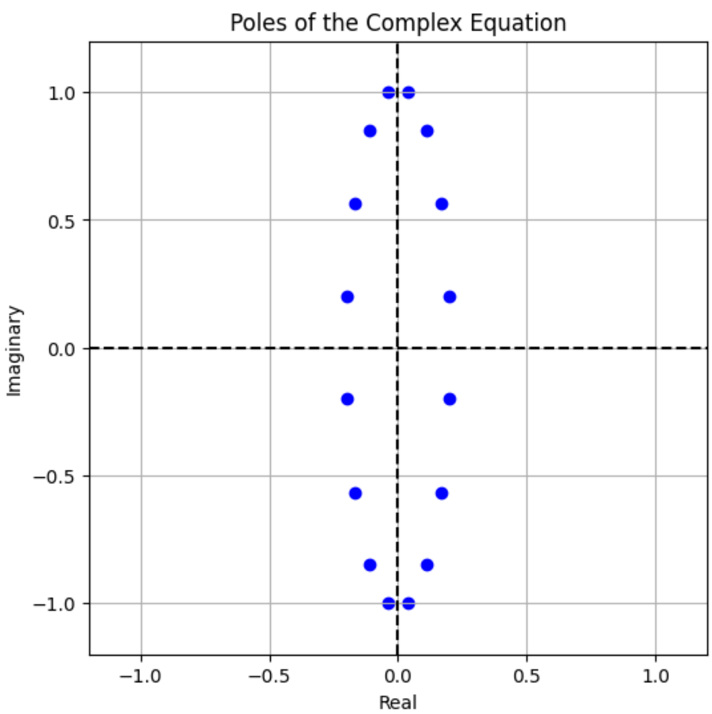


Figure 6.1: Poles of transfer function

For having a stable response, we use the left poles to make our Low pass filter:

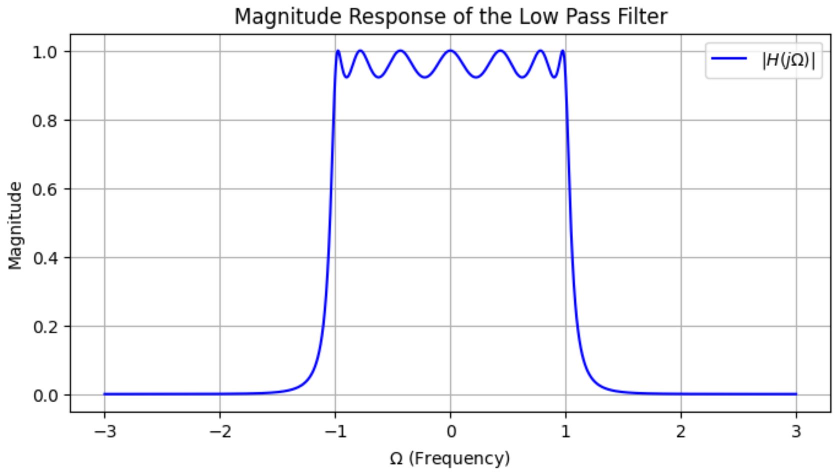


Figure 6.2: Low Pass Filter

The transfer function of this low pass filter is :

$$\frac{0.0186035985141495 + 2.63903482400352 \times 10^{-17} i}{\begin{array}{l} s^8 + s^7(1.03345640193969 + 8.88178419700125 \times 10^{-16} i) \\ + s^6(2.53401606735506 + 1.22124532708767 \times 10^{-15} i) \\ + s^5(1.89686680785906 + 3.33066907387547 \times 10^{-15} i) \\ + s^4(1.99971043140204 + 1.66533453693773 \times 10^{-15} i) \\ + s^3(0.991120598111362 + 1.11022302462516 \times 10^{-15} i) \\ + s^2(0.506033407360905 + 5.27355936696949 \times 10^{-16} i) \\ + s(0.128509401019156 + 2.0122792321331 \times 10^{-16} i) \\ + (0.0201774387355201 + 2.86229373536173 \times 10^{-17} i) \end{array}}$$

6.3 | BandStop Filter

We apply the above mentioned transform on the "s" variable in the equation of the Low pass analog filter. This gives us the following fiter magnitude response:

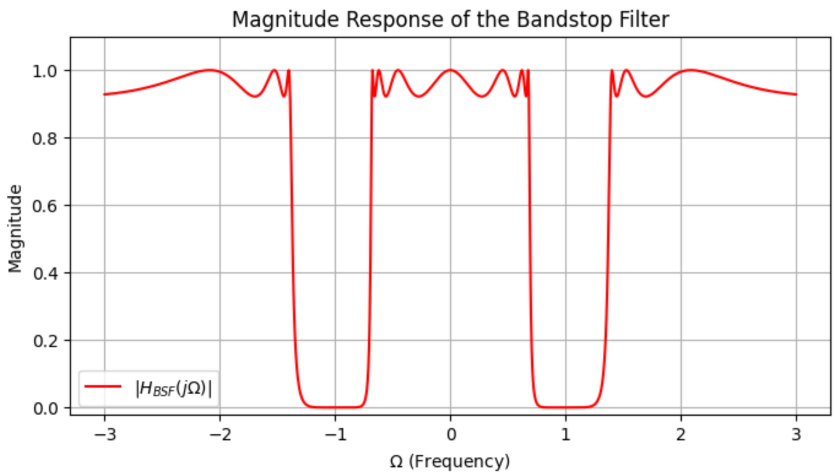


Figure 6.3: Band Stop Filter

The coefficients of the Band Stop Filter are:

Coefficient Index	Numerator Coefficient
0	$0.0186035985141495 + 2.63903482400352 \times 10^{-17}i$
1	0
2	$0.141135827368773 + 2.00209848141721 \times 10^{-16}i$
3	0
4	$0.468441805302565 + 6.64513500585541 \times 10^{-16}i$
5	0
6	$0.88845609244919 + 1.26032958934703 \times 10^{-15}i$
7	0
8	$1.05316474116278 + 1.4939789338215 \times 10^{-15}i$
9	0
10	$0.798981320665339 + 1.13340412466999 \times 10^{-15}i$
11	0
12	$0.378840986256406 + 5.37409230117541 \times 10^{-16}i$
13	0
14	$0.102645341122412 + 1.45608727009313 \times 10^{-16}i$
15	0
16	$0.0121674503707602 + 1.72602764047764 \times 10^{-17}i$

Table 6.1: Numerator Coefficients of the Analog BandStop Filter

Coefficient Index	Denominator Coefficient
0	$0.0201774387355201 + 2.86229373536173 \times 10^{-17}i$
1	$0.0911294661545408 + 1.4269612240339 \times 10^{-16}i$
2	$0.407540140690148 + 4.82334012662753 \times 10^{-16}i$
3	$0.958358711982703 + 1.34313793136054 \times 10^{-15}i$
4	$2.46160312273645 + 2.65071709931241 \times 10^{-15}i$
5	$3.7369169569038 + 5.16924226310427 \times 10^{-15}i$
6	$6.63651349067138 + 6.69682340726518 \times 10^{-15}i$
7	$6.95924536217842 + 9.59870162104264 \times 10^{-15}i$
8	$8.88595818411317 + 8.71017245392329 \times 10^{-15}i$
9	$6.59952193729017 + 9.10254468995249 \times 10^{-15}i$
10	$5.96816247696922 + 6.0223986932762 \times 10^{-15}i$
11	$3.18687061193783 + 4.4083683004621 \times 10^{-15}i$
12	$1.99076202045415 + 2.14370337750197 \times 10^{-15}i$

Table 6.2: Denominator Coefficients of the Analog BandStop Filter

7 | The Final Filter

7.1 | Cascading

We multiply the two frequency responses to get the following:
We see that the minimum value of the magnitude response in the passband is greater than 0.85 which satisfies the tolerance limits.

7.2 | Convert to Digital Filter

We use the bilinear transformation :

$$s \Rightarrow \frac{1 - z^{-1}}{1 + z^{-1}}$$

on the equation of the analog filter to discretize it.

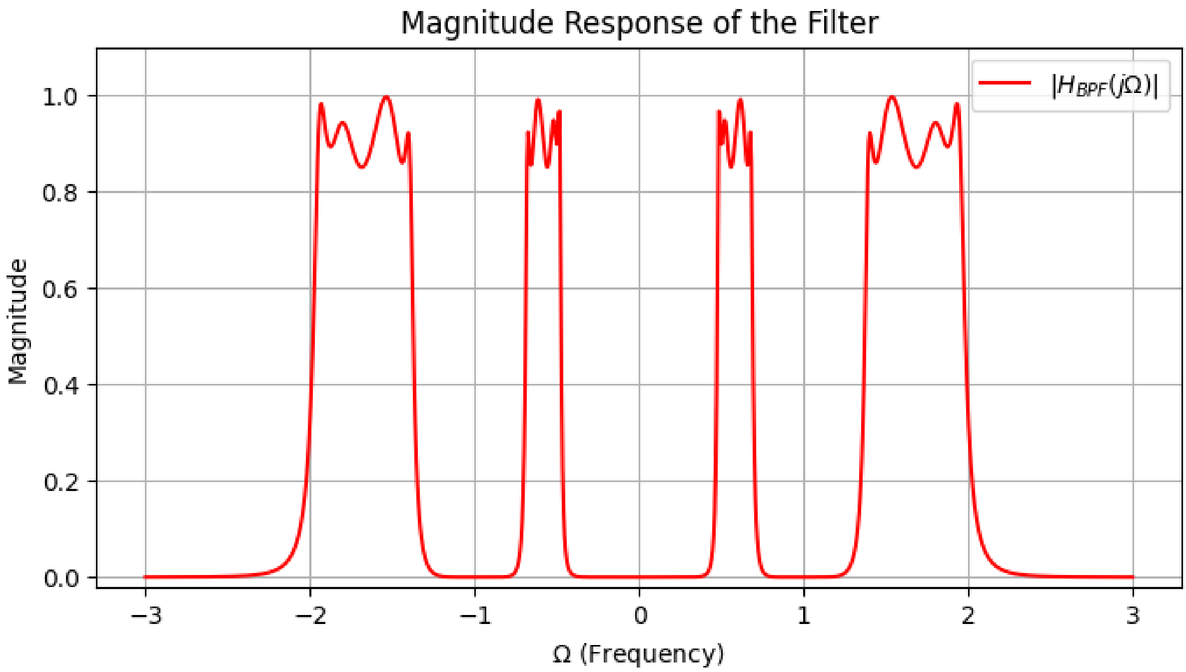


Figure 7.1: Multi Band Pass Filter Magnitude Response

8 | Digital Filter Coefficients

8.0.1 | Numerator Coefficients

$$
\begin{aligned}
&400.492746391776 + 9.11715745860703 \times 10^{-13}i, \\
&-357.235814058088 - 7.93449937581305 \times 10^{-13}i, \\
&5336.71429243583 + 1.14989814871858 \times 10^{-11}i, \\
&-4463.26962010863 - 9.35216534869489 \times 10^{-12}i, \\
&34233.322739064 + 6.92984769529983 \times 10^{-11}i, \\
&-26834.9649834084 - 5.26962094588015 \times 10^{-11}i, \\
&140727.050197576 + 2.66184998478429 \times 10^{-10}i, \\
&-103397.31050427 - 1.89615268999643 \times 10^{-10}i, \\
&417037.673096372 + 7.36443032971766 \times 10^{-10}i, \\
&-286805.377091127 - 4.91841428540394 \times 10^{-10}i, \\
&947992.768480947 + 1.56954966882044 \times 10^{-9}i, \\
&-608877.684333577 - 9.82632356776066 \times 10^{-10}i, \\
&1715907.90324051 + 2.68731092960961 \times 10^{-9}i, \\
&-1025786.82790273 - 1.57334661751813 \times 10^{-9}i, \\
&2531106.25237965 + 3.79059061791615 \times 10^{-9}i, \\
&-1401868.60868958 - 2.06439394277271 \times 10^{-9}i, \\
&3086328.56264375 + 4.46014621994259 \times 10^{-9}i, \\
&-1574010.85964123 - 2.24028187671897 \times 10^{-9}i, \\
&3134894.71527796 + 4.38789454625337 \times 10^{-9}i, \\
&-1460456.56128713 - 2.00960382158022 \times 10^{-9}i, \\
&2658893.09419463 + 3.59158936274029 \times 10^{-9}i, \\
&-1119745.99621369 - 1.47891800727319 \times 10^{-9}i, \\
&1878294.28755776 + 2.42164392151454 \times 10^{-9}i, \\
&-705210.620188971 - 8.8157941370456 \times 10^{-10}i, \\
&1096565.0287416 + 1.32650851242175 \times 10^{-9}i, \\
&-360205.400232412 - 4.1806500021838 \times 10^{-10}i, \\
&521598.276557817 + 5.79448039184498 \times 10^{-10}i, \\
&-145994.039203912 - 1.53759622268256 \times 10^{-10}i, \\
&197556.817201712 + 1.96698402794517 \times 10^{-10}i, \\
&-45303.6543038364 - 4.22154513637923 \times 10^{-11}i, \\
&57425.2139941209 + 4.99100830744032 \times 10^{-11}i, \\
&-10130.6851675937 - 8.12709129936235 \times 10^{-12}i, \\
&12048.2172669962 + 8.88292512276652 \times 10^{-12}i, \\
&-1455.19686843023 - 9.75504543058023 \times 10^{-13}i, \\
&1624.73102953919 + 9.84466457141011 \times 10^{-13}i, \\
&-100.918398757979 - 5.46661676767436 \times 10^{-14}i, \\
&105.812012621641 + 5.08003571508166 \times 10^{-14}i
\end{aligned}
$$

8.0.2 | Denominator Coefficients

$$
\begin{aligned}
&5078.9316682758 + 1.03656840644992 \times 10^{-11}i,\\
&-3882.37398872632 - 7.73561266801854 \times 10^{-12}i,\\
&42742.4269964987 + 8.1439840105495 \times 10^{-11}i,\\
&-31133.1826408517 - 5.78184214443227 \times 10^{-11}i,\\
&186248.825936374 + 3.31480249566859 \times 10^{-10}i,\\
&-128626.576655438 - 2.23717563244674 \times 10^{-10}i,\\
&546280.34040375 + 9.17800139606393 \times 10^{-10}i,\\
&-356479.036626524 - 5.88510655749986 \times 10^{-10}i,\\
&1196238.20065293 + 1.92734036788613 \times 10^{-9}i,\\
&-734939.230427795 - 1.17066866559002 \times 10^{-9}i,\\
&2062312.28182809 + 3.23581455924866 \times 10^{-9}i,\\
&-1188205.60691866 - 1.85074401400894 \times 10^{-9}i,\\
&2887193.14952745 + 4.45260854400679 \times 10^{-9}i,\\
&-1552941.52953662 - 2.37750925214243 \times 10^{-9}i,\\
&3345206.65154086 + 5.06586671480898 \times 10^{-9}i,\\
&-1671052.47442486 - 2.49875554605353 \times 10^{-9}i,\\
&3245857.40576505 + 4.762779390759e - 9i,\\
&-1496894.76565586 - 2.14357984766084 \times 10^{-9}i,\\
&2656619.81712529 + 3.67474837728858 \times 10^{-9}i,\\
&-1123411.03056094 - 1.48657073091413 \times 10^{-9}i,\\
&1842090.96124892 + 2.29484267597604 \times 10^{-9}i,\\
&-708870.343172402 - 8.17353230328511 \times 10^{-10}i,\\
&1085175.68157742 + 1.12976517375108 \times 10^{-9}i,\\
&-376829.494460068 - 3.42242490164359 \times 10^{-10}i,\\
&544439.830061774 + 4.13437137225519 \times 10^{-10}i
\end{aligned}
$$

9 | Comparison Between Filter Type I and II

We realise that for the same tolerance, butterworth filter has a higher N value than chebyschev filter. For getting a tolerance of 0.15 for the bandpass as the butterworth filter, we got a N value of 8. But in chebyschev we get an N value of 8 and 10 for tolerance much less, almost half of that of butterworth filter (0.078). This implies that the Chebyshev filter achieves a steeper roll-off (faster transition from passband to stopband) compared to the Butterworth filter for the same or even lower order N. Chebyshev filters can achieve the same filtering effect as Butterworth with a lower filter order, leading to less computational complexity and fewer components in analog circuits. This is why Chebyshev filters are preferred when narrow transition bands are required. The improved efficiency comes at a cost – Chebyshev filters introduce ripple in the passband, while Butterworth filters have a maximally flat response.

10 | Reviewers and Reviews

- Aman Rishal C H (22b3914): Has used parallel bandpass filters and assumed that tolerances almost wont matter which is a good approximation. All parameters mentioned and the final filter meets all reqired specifications.
- Shikhar Ashutosh Moondra (22b0688) : Reviewed the report. He has used parallel bandpass filters as well. Coefficients arent mentioned in the report(i mentioned about it to him) but the filter design seems to be right based on the approach and the final plots.

- Sarvadnya Purkar (22b4232) : Reviwed the code. Parallel bandpass filters used. Again Coefficients aren't specifically mentioned but equation is present in the code output.